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POLARIZED QUASI-OPTICAL PHASE SHIFTER

by

M.S. Yanovskiy and B.N. Knyaz'kov

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А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yë or ë.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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POLARIZED QUASI-OPTICAL PHASE SHIFTER

M. S. Yanovskiy and B. N. Knyaz'kov

A description of a polarized phase shifter for a quasi-optical transmission line is given. Found is the dependence of the phase shift on the turning angle of the half-wave phase section. The operation of the phase shifter in a frequency band is examined.

INTRODUCTION

Widely used in SHF waveguide channels are polarized phase shifters [1], in which the half-wave differential phase section is turned to the field of a wave with circular polarization between two quarter-wave sections. The phase shift Φ introduced by such a phase shifter is uniquely connected with the angle Ψ of the turn of the half-wave phase section ($\Phi = 2\Psi$) and in a wide band does not depend on frequency.

The direct transfer of the idea of construction of a waveguide polarized phase shifter into the quasi-optical region for light guides encounters difficulties in connection with the fact that at the present time here there are no acceptable analogs of the waveguide phase sections. The sections consisting of a set of parallel dielectric plates are very complex to manufacture and adjust, and the use of anisotropic crystals is connected with the introduction of great absorption. Furthermore, it is difficult to match both indicated types of sections with the transmission line, especially in the frequency band.

In connection with this, it was proposed [2] to use in the polarized quasi-optical phase shifter reflecting phase sections in the form of wire lattices behind which are placed flat metallic mirrors [3].

PRINCIPAL OF OPERATION AND SYSTEM OF THE PHASE SHIFTER

The system of the phase shifter, constructed on a base of a hollow dielectric light guide [4], is schematically shown on Fig. 1. Entering into the input of the phase shifter is a linear-polarized oscillation, which is the basic mode EH_{11} of the light guide - a wave with a practically flat phase front and amplitude distribution which decreases toward the periphery of the line according to Bessel's law. Wires of the polarizing lattice 4 are prependicular to the electrical vector of the wave, and the latter passes through this lattice without an attenuation and then enters into the quarter-wave phase section 1, designed for the conversion of the linear-polarized oscillation into an oscillation polarized over a circle. The wave entering into section 1 can be decomposed into two components - one, polarized in an azimuthal plane parallel to wires of the lattice, and the other, perpendicular to it. The first undergoes a great reflection from the lattice, whereas the second passes through the lattice practically without attenuation. This (latter) component is reflected by a metallic mirror, again passes through the lattice and further is propagated jointly with the component which is reflected from the lattice. The relationship of amplitudes of these components is determined by the angle ξ between the plane of oscillaiton of the incident wave and azimuthal plane in parallel to the wires and axis of the light guide. Their equality is achieved when $\xi = \pm 45°$.

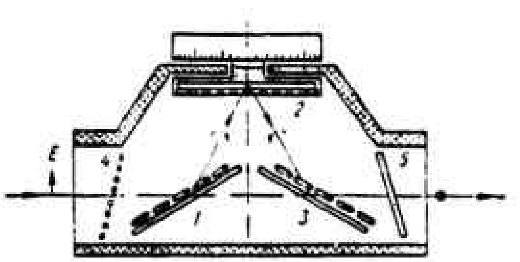

Fig. 1. Diagram of system of phase shifter.

The distance between the lattice and reflector (1) is selected so that the difference in the movement for two components would equal $\lambda/4$, and thus at the output of the phase section 1 we have a wave polarized over the circle. The differential phase shift Δ in the section is connected with distance d between the wire lattice and reflector and with angle θ of incidence of the wave on the section by the relation

$$\Delta=4\pi\frac{d}{\lambda}\cos\theta.$$

The wave polarized over the circle enters into the turning reflecting phase section 2, in which the distance between the wire lattice and reflector is selected $\Delta_2=\pi$ (half-wave section) corresponding to the differential phase shift. The phase of the wave reflected from section 2 polarized over the circle is already found in a definite relationship with the turning angle of its lattice.

Further, the wave polarized over the circle enters into the quarter-wave section 3 fulfilled similar to section 1. Here with reflection the wave is converted into a linear-polarized wave, which enters into the output, passing through lattice 5, which eliminates the secondary component the electrical vector of which lies in the azimuthal plane parallel to the wires. The latter is formed due to the deviation in the difference of movement of beams in the sections from nominal values equal to $\lambda/4$ and $\lambda/2$. Sections 1 and 3, in conformity with the recommendations of work [5], are positioned orthogonally. correspondingly, the lattices 4 and 5 are located orthogonally.

We can establish the relationship between the phase of the wave at the output and the turning angle of the half-wave phase section 2 after a more detailed examination of the work of the phase section.

PHASE SECTION

Let us examine the reflecting phase section under the assumption that it consists of an ideally conducting surface, positioned in front of which is an anisotropically conducting surface in parallel to the first one. Let us assume that the anisotropically conducting surface has an infinite surface conductivity in one direction and zero conductivity in a perpendicular direction.

Let us position the rectangular coordinate system x, y, z in such a way that plane x, y coincides with the anisotropically conducting surface (Fig. 2), and the y axis is parallel to wires of the lattice. The relation $\vec{r}_i = \alpha\vec{x} + \beta\vec{y} + \gamma\vec{z}$ is a single vector in the direction of propagation of the incident wave, and E_x, E_y, and E_z are projections of the electrical vector on the coordinate axes. Indices i, r and t refer to the incident, reflected and passed waves, respectively.

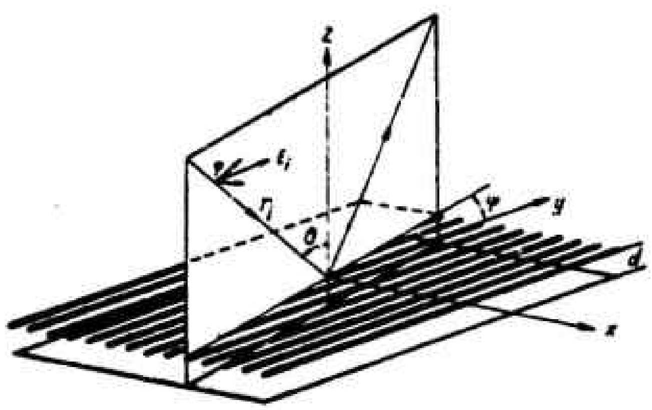

Fig. 2. Position of phase section with respect to coordinate system.

In these designations in work [3], with the examination of the wire lattice, the following relations for projections of the electrical vector of the passed wave are obtained:

$$E_{xt} = E_{xi} + \frac{\alpha\beta}{1-\beta^2} E_{yi}$$
$$E_{yt} = 0, \qquad (1)$$
$$E_{zt} = -\frac{\alpha}{\gamma} E_{xi}$$

Let us use this result for finding conditions of the complete reflection of the wave by the lattice. In other words, let us find the relationship between the azimuth of oscillation φ and, corresponding to it, the turning angle of the lattice Ψ (angle between wires of the lattice and plane of incidence) at which the lattice completely reflects the wave incident onto it.

Having assumed that $E_{z}=0$ and having used (1), we find

$$\frac{E_{x1}}{E_{yt}}=-\frac{\alpha\beta}{1-\beta^2}. \qquad (2)$$

α, β and γ can be expressed in terms of angle of incidence of the wave onto the lattice plane Θ and turning angle of the lattice Ψ:

$$\begin{aligned} \alpha &= -\sin\Theta\sin\Psi, \\ \beta &= \sin\Theta\cos\Psi, \\ \gamma &= \cos\Theta. \end{aligned} \qquad (3)$$

Let us decompose the incident wave into two components - one with amplitude $E_i\cos\varphi$, lying in the incident plane, and the other with amplitude $E_i\sin\varphi$, perpendicular to it. Let us express components E_{xt} and E_{yt} in terms of these components, the angle of incidence Θ and turning angle of the lattice Ψ. Their ratio

$$\frac{E_{xt}}{E_{yt}}=\frac{-\cos\varphi\cos\Theta\sin\Psi+\sin\varphi\cos\Psi}{\cos\varphi\cos\Theta\cos\Psi+\sin\varphi\sin\Psi}. \qquad (4)$$

Having equated the right sides of (2) and (4) and used expressions (3), we find the connection between the turning angle of the plane of the anisotropic reflection and turning angle of the lattice

$$\varphi=\operatorname{arc\,tg}\left[\frac{1}{\cos\Theta}\operatorname{tg}\Psi\right]. \qquad (5)$$

With normal incidence of the beam onto the face section $(\cos\Theta=1)$ $\varphi=\Psi$.

INVESTIGATION OF THE PHASE SHIFTER IN THE FREQUENCY BAND

The phase shift introduced by the polarized phase shifter, as is known [1], is equal to double the turning angle of the anisotropy of the half-wave phase section. Thus if signal $E\sin\omega t$, enters into the input of the phase shifter, then the signal at its output will be

$$e = E \sin\left\{\omega t + 2 \operatorname{arc\,tg}\left[\frac{1}{\cos\Theta} \operatorname{tg} \Psi_2\right]\right\}. \qquad (6)$$

The constant phase shift in (6) is omitted.

The dependence of the phase shift introduced by the phase shifter on the turning angle Ψ_2 of the half-wave phase section is given in Fig. 3 for angles of incidence of the beam onto this section equal to 0° (curve 1) 30° (curve 2), 45° (curve 3) and 60° (curve 4).

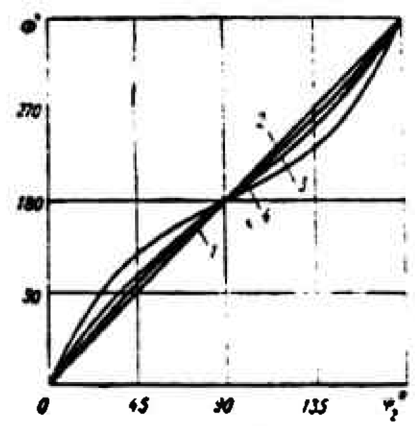

Fig. 3. Dependence of the phase shift on turning angle of the half-wave phase section.

The scale of the phase shifter is calculated on the basis of formula (6), and one turn of the scale corresponds to a half of a turn of the moveable section and to a phase shift of 360°. At small angles of incidence the nonlinearity of the scale is not great. Thus when $\Theta_2 = 30^\circ$ the division corresponding to one electrical degree occupies in different sections scales of 50 to 70 angular minutes.

Having used the relation (5), it is possible also to obtain the expression for the setting angle Ψ_1 Ψ_3 of lattices of quarter-wave sections 1 (3) with respect to the plane of incidence, if the azimuth of oscillation of the incident (reflected) wave $\varphi_1(\varphi_3)$.

$$\operatorname{tg} \Psi = \cos\Theta \, \frac{\operatorname{tg}\varphi \pm 1}{1 \pm \operatorname{tg}\varphi}.$$

The phase shift being introduced is in conformity with that read along the calculated scale of the phase shifter only when the sections give nominal differential phase shifts equal to $\pi/2$ and π radians. In the operation of the phase shifter in the frequency band without retuning of phase sections, these shifts are different from the nominal. Let us denote them by $\pi/2+\delta_1$, $\pi+\delta_2$ and $\pi/2+\delta_3$. We can obtain the following expression for the oscillation at the output of the phase shifter with an orthogonal position [5] of the quarter-wave sections

$$e=E\cos\frac{\delta_1}{2}\cos\frac{\delta_2}{2}\cos\frac{\delta_3}{2}\sin(\omega t+2\varphi_2)-E\sin\frac{\delta_1-\delta_3}{2}\sin\frac{\delta_2}{2}\sin\omega t+ \\ +E\sin\frac{\delta_1}{2}\cos\frac{\delta_2}{2}\sin\frac{\delta_3}{2}\sin(\omega t-2\varphi_2). \qquad (7)$$

Here the first term describes the useful signal the phase of which $(2\varphi_2)$ is determined by the turning angle of the plane of anisotropy. The second term becomes zero when $\delta_1=\delta_3$.

If we consider that the level of secondary oscillations determined by the second component (7), which contains $\delta_1-\delta_3$ in the argument of the sine, is considerably less than the definable third term, it is possible to find that the greatest error of the phase shifter caused by a deviation of the phase shift in the section consists of $\frac{\pi^2}{16}\left(\frac{\Delta f}{f_0}\right)^2$, where $\Delta f/f_0$ is the relative frequency difference. This error consists of $\pm 1^\circ$ in a frequency band of $\pm 15\% f_0$ and $\pm 1.5^\circ$ in the frequency band of $\pm 20\% f_0$.

We conducted an experimental study of a phase shifter made on the basis of a hollow dielectric light guide with an internal diameter of 20 mm, in phase sections of which lattices of tungsten wire $\varnothing 0.01$ mm with a pitch of 0.06 mm were used. In the scheme of the quasi-optical Michelson interferometer, a comparison was made of the phase shift introduced by the phase shifter and standard reflector, which is a fixed mirror with a calibrated micrometric reading of movement. Such a comparison was conducted in the range of 1.1-1.52 mm, and the phase sections were tuned to the nominal phase shifts on a wave of 1.3 mm.

At the frequency of tuning of the phase sections, the phase shift introduced by the phase shifter differed from that read on its scale by not more than $\pm 1^{\circ}$. On edges of the indicated range, this difference reached $\pm 2^{\circ}$, which is in good agreement with the estimate conducted according to formula (7).

The change in the signal at the output of the phase shifter, in the process of phase regulation, does not exceed 0.1 dB.

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15 May 1969

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